BICEP/Keck and cosmological attractors

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Our goals:

1) Discussing inflation and its status after Planck2018 and BICEP/Keck2021

2) Identifying simplest models, where a single parameter is sufficient to describe all presently available data

3) Finding "future-safe" models, which have a fighting chance to describe all data to be obtained in the next one or two decades

4) Implementing these models in supergravity and string theory

Testing predictions of inflation

1) **The universe is flat, $\Omega = 1$**. (In the mid-90's, the consensus was that $\Omega = 0.3$, until the discovery of dark energy confirming inflation.)

2) The observable part of the universe is **uniform** (homogeneous).

3) It is **isotropic**. In particular, it does not rotate. (Back in the 80's we did not know that it is uniform and isotropic at such an incredible level.)

4) Perturbations produced by inflation are adiabatic

5) Unlike perturbations produced by cosmic strings, inflationary perturbations lead to many **peaks in the spectrum**

6) The large angle TE anti-correlation (WMAP, Planck) is a distinctive signature of **superhorizon fluctuations** (Spergel, Zaldarriaga 1997), ruling out many alternative possibilities

7) Inflationary perturbations should have a **nearly flat (but not exactly flat) spectrum**. A small deviation from flatness is one of the distinguishing features of inflation. It is as significant for inflationary theory as the asymptotic freedom for the theory of strong interactions

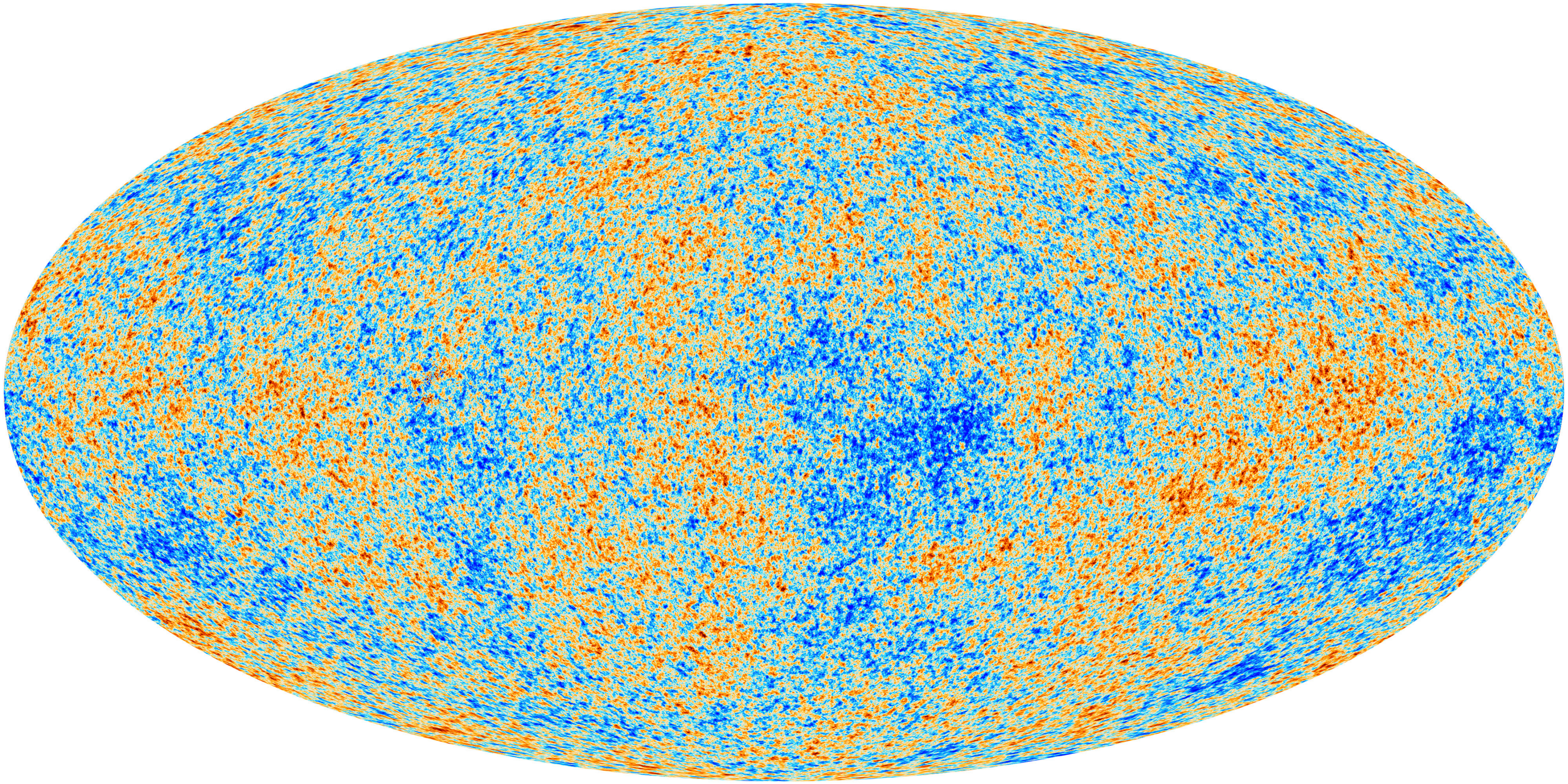
8) **Inflation produces scalar perturbations** and **tensor perturbations** with nearly flat spectrum, and it **does not produce vector perturbations**. There are certain relations between the properties of scalar and tensor perturbations

9) In the early 80's it seemed that inflation is ruled out because scalar perturbations are not observed at the expected level 10^{-3} required for galaxy formation. Thanks to dark matter, smaller perturbations are sufficient, and they were **found by COBE**.

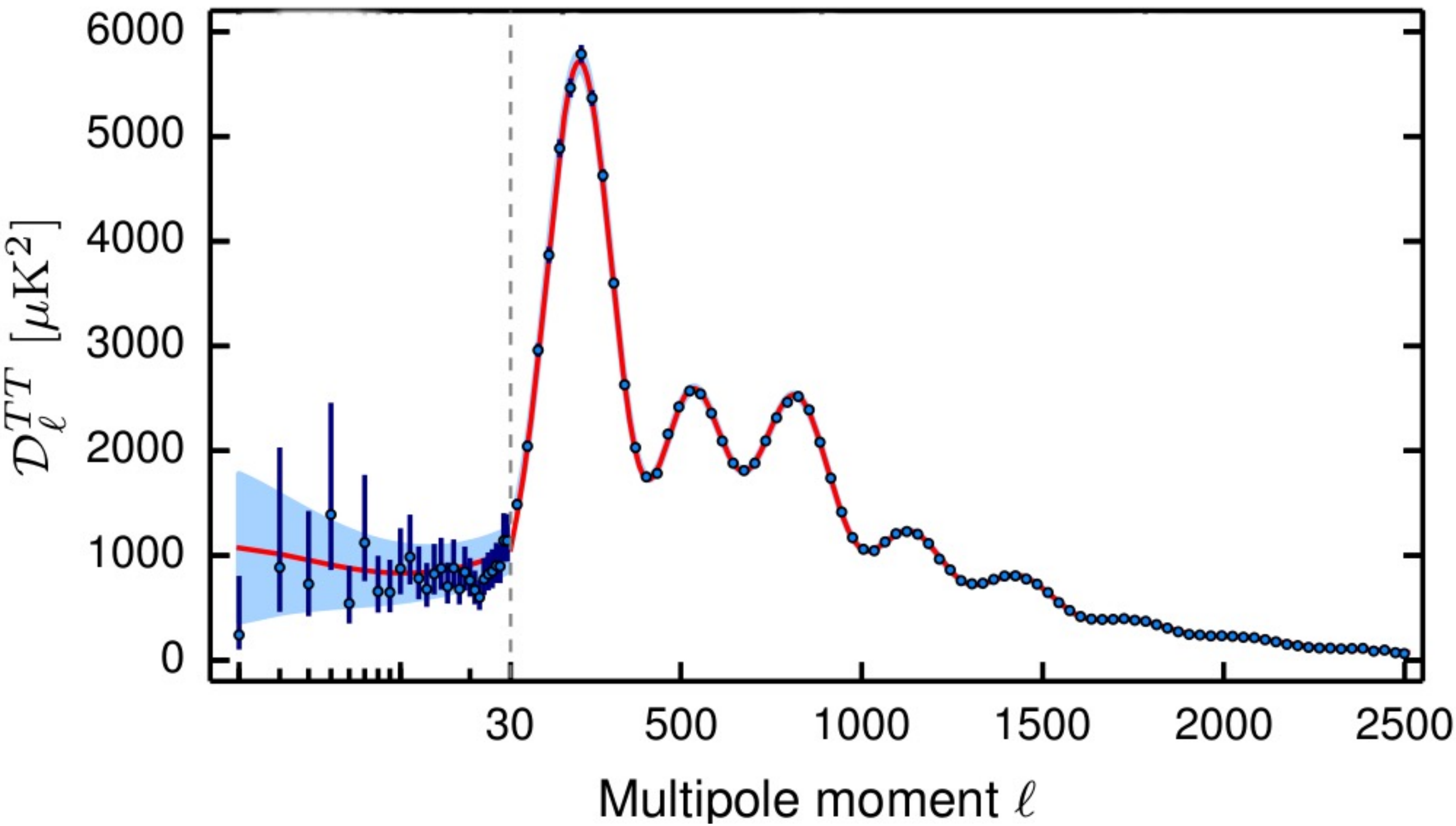
10) Scalar perturbations are **Gaussian**. In non-inflationary models, the parameter f_{NL}^{local} describing the level of local non-Gaussianity can be as large as 10^4, but it is predicted to be O(1) in all single-field inflationary models. **Confirmed by Planck.** Prior to the Planck2013 data release, there were rumors that $f_{NL}^{local} \gg O(1)$, which would rule out **all** single field inflationary models

Planck 2013: Perturbations of temperature

This is an image of quantum fluctuations produced 10^{-35} seconds after the Big Bang. These tiny fluctuations were stretched by inflation to incredibly large size, and now we can observe them using all sky as a giant photographic plate!!!



Planck 2015: TT spectrum (blue dots) and predictions of inflationary theory (red line)



Inflation and Planck 2018

$$\Omega = 1.009 \pm 0.0018$$

Planck + SPT + BAO

Universe is flat with accuracy better than 10^{-2}

$$n_s = 0.965 \pm 0.004$$

Spectrum of perturbations is nearly flat

Non-inflationary HZ spectrum with $n_s = 1$ is ruled out at a better than 6σ level, just as predicted in 1981 by Mukhanov and Chibisov. (This is an important prediction of inflation, similar to asymptotic freedom in QCD.)

$$f_{\mathrm{NL}}^{\mathrm{local}} = 0.91 \pm 5$$

Agrees with predictions of the simplest inflationary models with accuracy $O(10^{-4})$.

An impressive success of inflationary theory

Can we test inflation even better ?

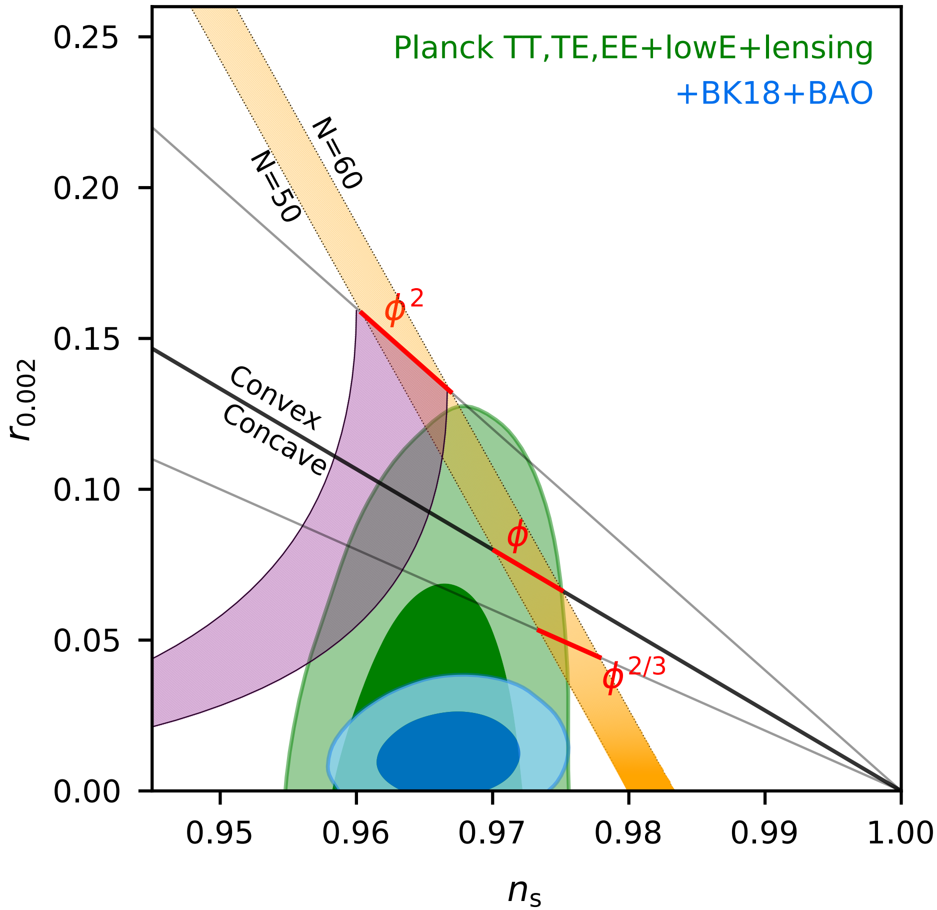
B-modes: a special polarization pattern which can be produced by gravitational waves generated during inflation. A discovery of the gravitational waves of this type could provide a strong **additional** evidence in favor of inflation.

BICEP/Keck and other experiments

A non-discovery of B-modes is fine too: many inflationary models predict a very small amplitude of the gravitational waves.

Improved constraints on primordial gravitational waves using Planck, WMAP, and BICEP/Keck observations through the 2018 observing season

P.A.R. Ade et al, https://arxiv.org/pdf/2110.00483.pdf



$$r_{0.05} < 0.036 \ \text{at} \ 95\% \ \text{confidence}$$

$$r_{0.05} = 0.014^{+0.010}_{-0.011}$$

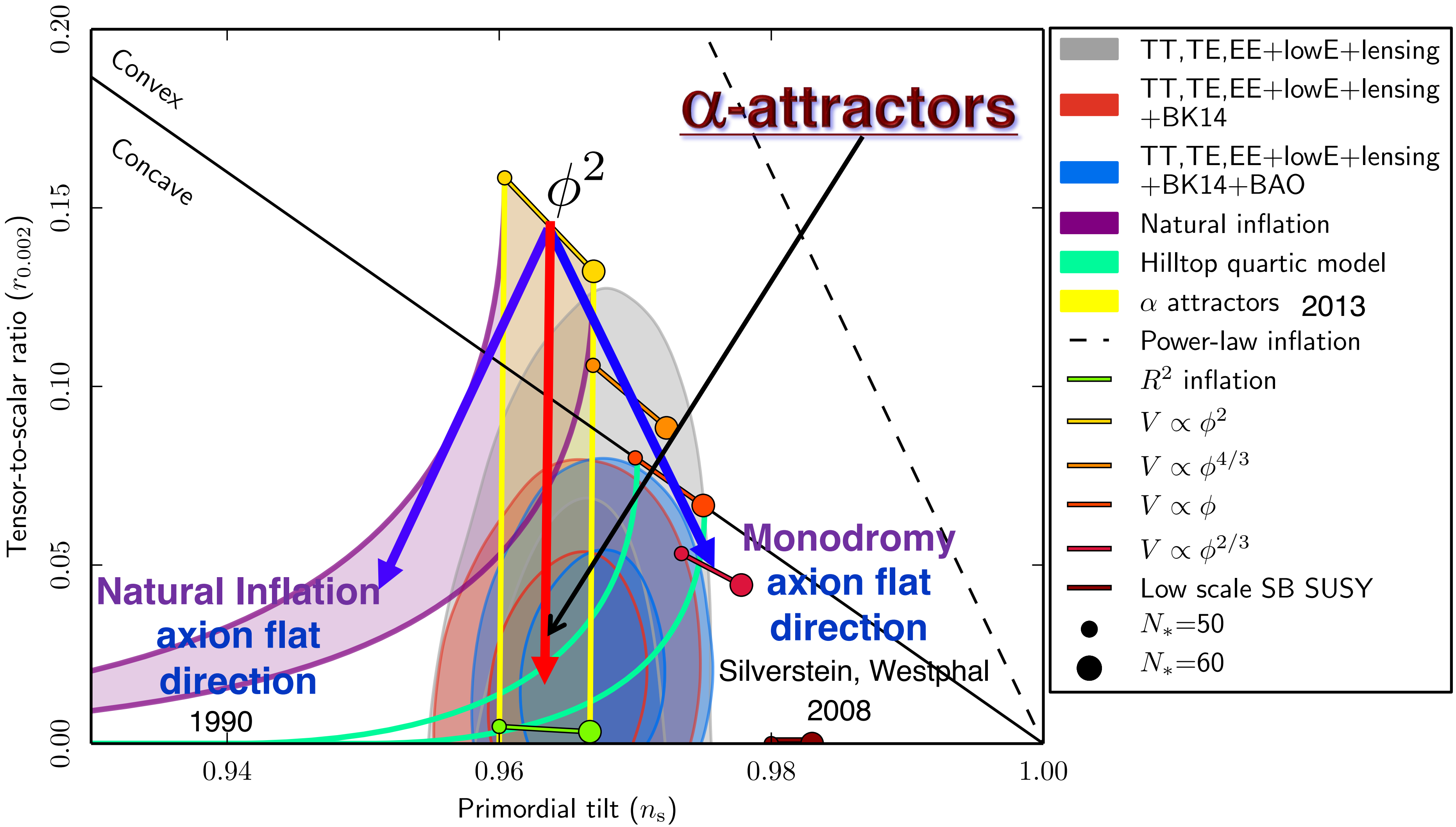
$$\sigma(r) = 0.009$$

projected to reach $\sigma(r) \sim 0.003$ within five years

Planck 2018: Not all theories fit the data

α-attractors, Starobinsky, Higgs, fiber inflation, D-brane inflation

saxion flat direction: **plateau potentials**



One can fit all Planck data by a polynomial, with inflation starting at the Planck density

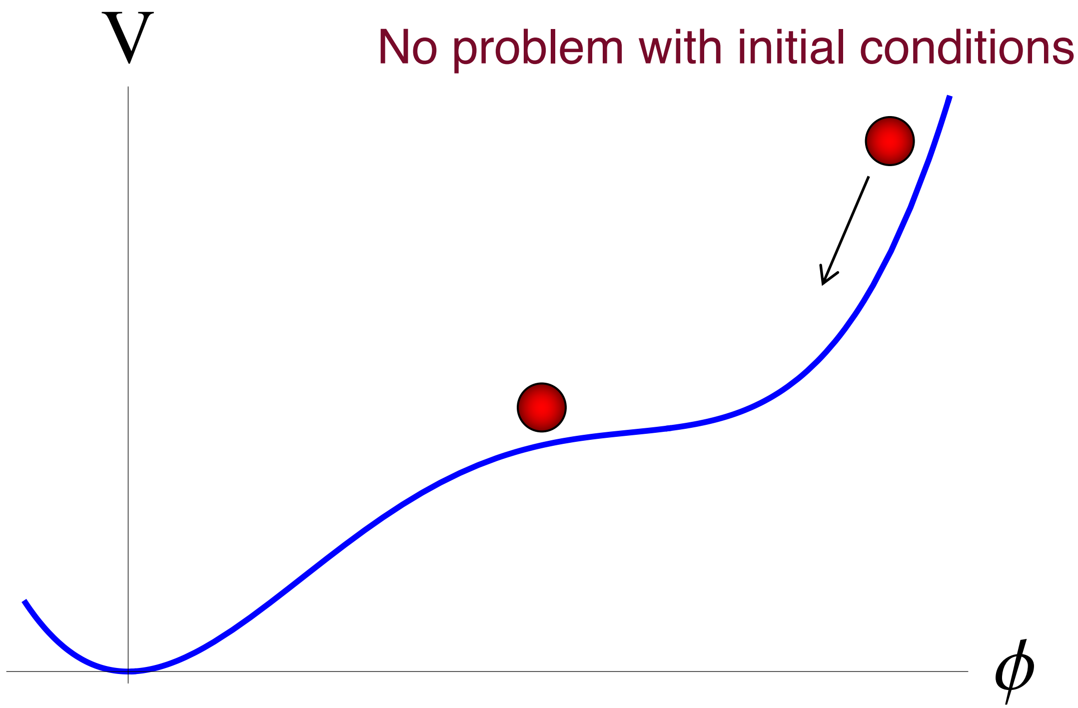
$$V = \frac{m^2\phi^2}{2}\left(1 - a\phi + b\phi^2\right)$$

Destri, de Vega, Sanchez, 2007
Nakayama, Takahashi and Yanagida, 2013
Kallosh, AL, Westphal 2014
Kallosh, AL, Roest, Yamada 1705.09247

3 observables: A_s, n_s, r

3 parameters: m, a, b

Example: $m = 10^{-5}$, a = 0.12, b=0.29



But it is better to have models which require **no more than 1 or 2 free parameters**

List of models favored by Planck2018

Inflationary model	Potential $V(\phi)$	Parameter range	$\Delta\chi^2$	$\ln B$
$R + R^2/(6M^2)$	$\Lambda^4\left(1 - e^{-\sqrt{2/3}\phi/M_{\rm Pl}}\right)^2$	...	...	...
Power-law potential	$\lambda M_{\rm Pl}^{10/3}\phi^{2/3}$	...	2.8	−2.6
Power-law potential	$\lambda M_{\rm Pl}^3\phi$	...	2.5	−1.9
Power-law potential	$\lambda M_{\rm Pl}^{8/3}\phi^{4/3}$	...	10.4	−4.5
Power-law potential	$\lambda M_{\rm Pl}^2\phi^2$	...	22.3	−7.1
Power-law potential	$\lambda M_{\rm Pl}\phi^3$	...	40.9	−19.2
Power-law potential	$\lambda\phi^4$	...	89.1	−33.3
Non-minimal coupling	$\lambda^4\phi^4 + \xi\phi^2 R/2$	$-4 < \log_{10}\xi < 4$	3.1	−1.6
Natural inflation	$\Lambda^4\left[1 + \cos(\phi/f)\right]$	$0.3 < \log_{10}(f/M_{\rm Pl}) < 2.5$	9.4	−4.2
Hilltop quadratic model	$\Lambda^4\left(1 - \phi^2/\mu_2^2 + \dots\right)$	$0.3 < \log_{10}(\mu_2/M_{\rm Pl}) < 4.85$	1.7	−2.0
Hilltop quartic model	$\Lambda^4\left(1 - \phi^4/\mu_4^4 + \dots\right)$	$-2 < \log_{10}(\mu_4/M_{\rm Pl}) < 2$	−0.3	−1.4
D-brane inflation ($p = 2$)	$\Lambda^4\left(1 - \mu_{\rm D\,2}^2/\phi^p + \dots\right)$	$-6 < \log_{10}(\mu_{\rm D\,2}/M_{\rm Pl}) < 0.3$	−2.3	1.6
D-brane inflation ($p = 4$)	$\Lambda^4\left(1 - \mu_{\rm D\,4}^4/\phi^p + \dots\right)$	$-6 < \log_{10}(\mu_{\rm D\,4}/M_{\rm Pl}) < 0.3$	−2.2	0.8
Potential with exponential tails	$\Lambda^4\left[1 - \exp(-q\phi/M_{\rm Pl}) + \dots\right]$	$-3 < \log_{10} q < 3$	−0.5	−1.0
Spontaneously broken SUSY	$\Lambda^4\left[1 + \alpha_h \log(\phi/M_{\rm Pl}) + \dots\right]$	$-2.5 < \log_{10}\alpha_h < 1$	9.0	−5.0
E-model ($n = 1$)	$\Lambda^4\left\{1 - \exp\left[-\sqrt{2}\phi\left(\sqrt{3\alpha_1^{\rm E}}M_{\rm Pl}\right)^{-1}\right]\right\}^{2n}$	$-2 < \log_{10}\alpha_1^{\rm E} < 4$	0.2	−1.0
E-model ($n = 2$)	$\Lambda^4\left\{1 - \exp\left[-\sqrt{2}\phi\left(\sqrt{3\alpha_2^{\rm E}}M_{\rm Pl}\right)^{-1}\right]\right\}^{2n}$	$-2 < \log_{10}\alpha_2^{\rm E} < 4$	−0.1	0.7
T-model ($m = 1$)	$\Lambda^4\tanh^{2m}\left[\phi\left(\sqrt{6\alpha_1^{\rm T}}M_{\rm Pl}\right)^{-1}\right]$	$-2 < \log_{10}\alpha_1^{\rm T} < 4$	−0.1	0.1
T-model ($m = 2$)	$\Lambda^4\tanh^{2m}\left[\phi\left(\sqrt{6\alpha_2^{\rm T}}M_{\rm Pl}\right)^{-1}\right]$	$-2 < \log_{10}\alpha_2^{\rm T} < 4$	−0.4	0.1

Subsequent developments:

Inflationary model	Potential $V(\phi)$	Parameter range	$\Delta\chi^2$	$\ln B$
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What is the meaning of α-attractors?

Kallosh, AL, Roest 2014

Start with the simplest chaotic inflation model

$$\frac{1}{\sqrt{-g}}\mathcal{L} = \frac{1}{2}R - \frac{1}{2}\partial\phi^2 - \frac{1}{2}m^2\phi^2$$

Modify its kinetic term

$$\frac{1}{\sqrt{-g}}\mathcal{L} = \frac{1}{2}R - \frac{1}{2}\frac{\partial\phi^2}{(1-\underline{\frac{\phi^2}{6\alpha}})^2} - \frac{1}{2}m^2\phi^2$$

Switch to canonical variables $\phi = \sqrt{6\alpha}\,\tanh\frac{\varphi}{\sqrt{6\alpha}}$

The potential becomes

$$V = 3\alpha\, m^2 \tanh^2\frac{\varphi}{\sqrt{6\alpha}}$$

This model (T-model) is consistent with observational data for m ~ 10^{-5} and <u>any</u> value of α smaller than O(7).

What is the meaning of α-attractors?

More generally:

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{R}{2} - \frac{(\partial_\mu \phi)^2}{2\left(1 - \frac{\phi^2}{6\alpha}\right)^2} - V(\phi)$$

In canonical variables

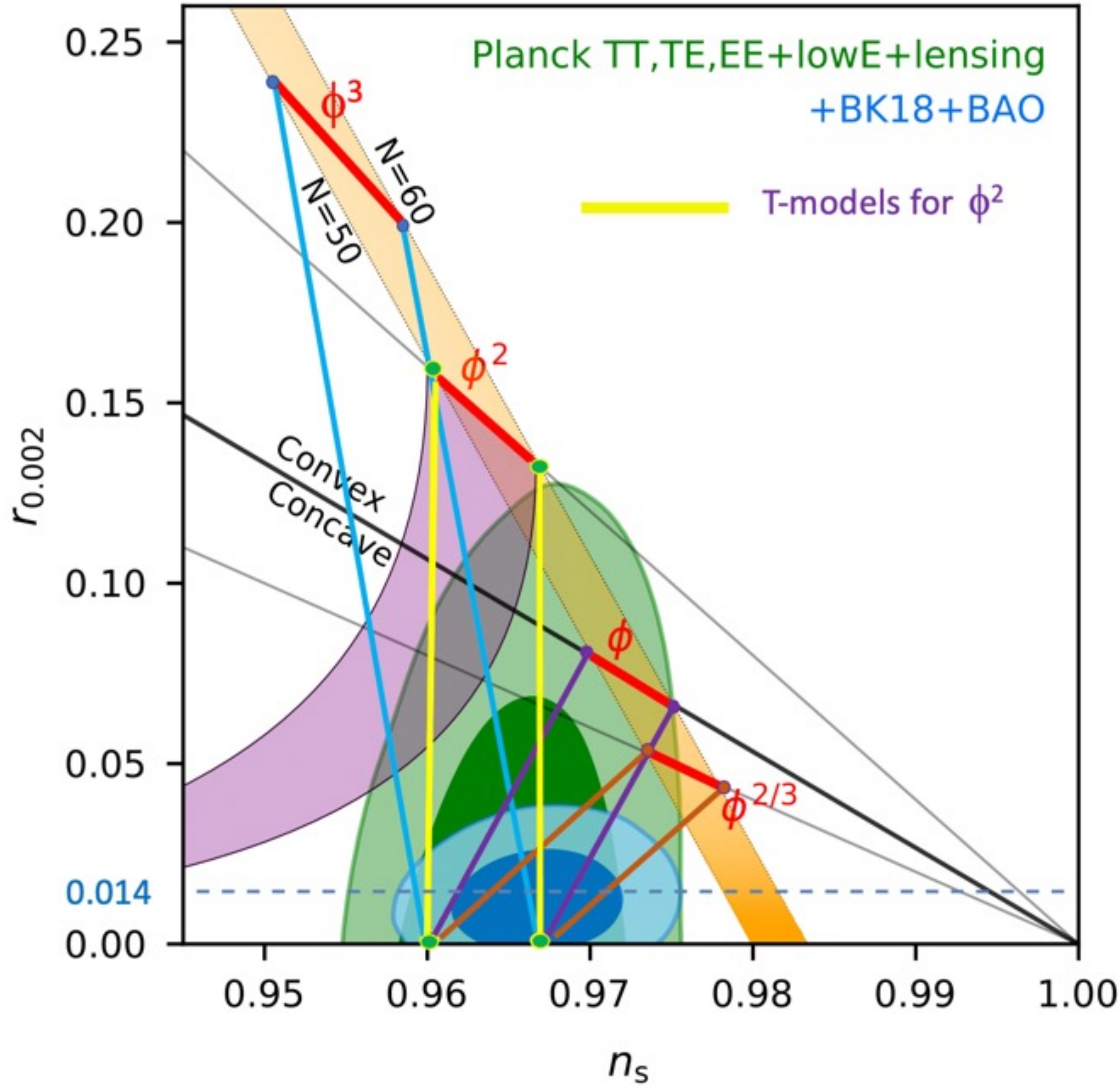
$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{R}{2} - \frac{(\partial_\mu \varphi)^2}{2} - V\left(\sqrt{6\alpha}\,\tanh\frac{\varphi}{\sqrt{6\alpha}}\right)$$

Asymptotically at large values of the inflaton

$$V(\varphi) = V_0 - 2\sqrt{6\alpha}\, V_0'\; e^{-\sqrt{\frac{2}{3\alpha}}\varphi}$$

Here $V_0' = \partial_\phi V|_{\phi=\sqrt{6\alpha}}$ This factor can be absorbed in the redefinition (shift) of the field. **At small α, values of n_s and r depend only on V_0 and α**, not on the shape of V(ϕ).

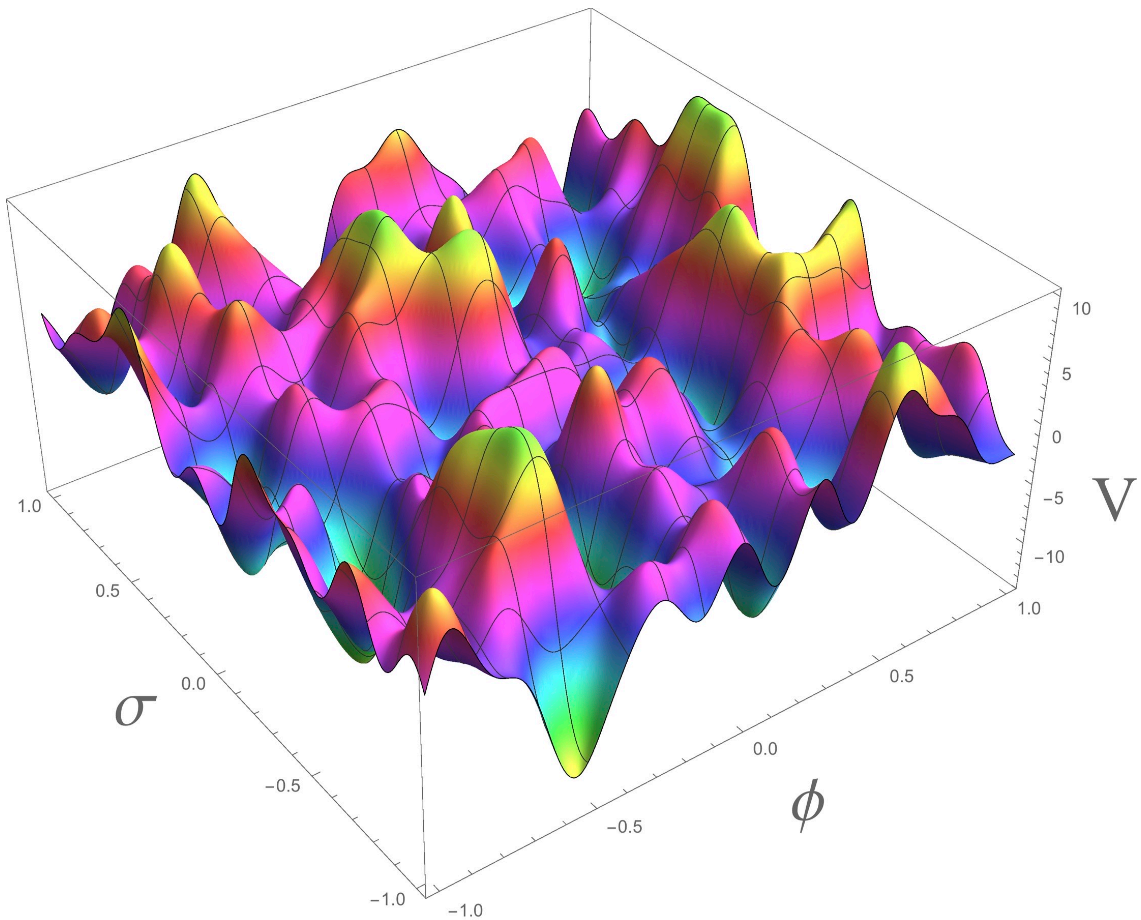
$$n_s = 1 - \frac{2}{N_e}\,, \qquad r = \frac{12\alpha}{N_e^2}$$



Planck TT,TE,EE+lowE+lensing
+BK18+BAO
T-models for ϕ^2
ϕ^3
N=60
N=50
ϕ^2
Convex
Concave
ϕ
$\phi^{2/3}$
0.014
$r_{0.002}$
n_s
0.25
0.20
0.15
0.10
0.05
0.00
0.95
0.96
0.97
0.98
0.99
1.00

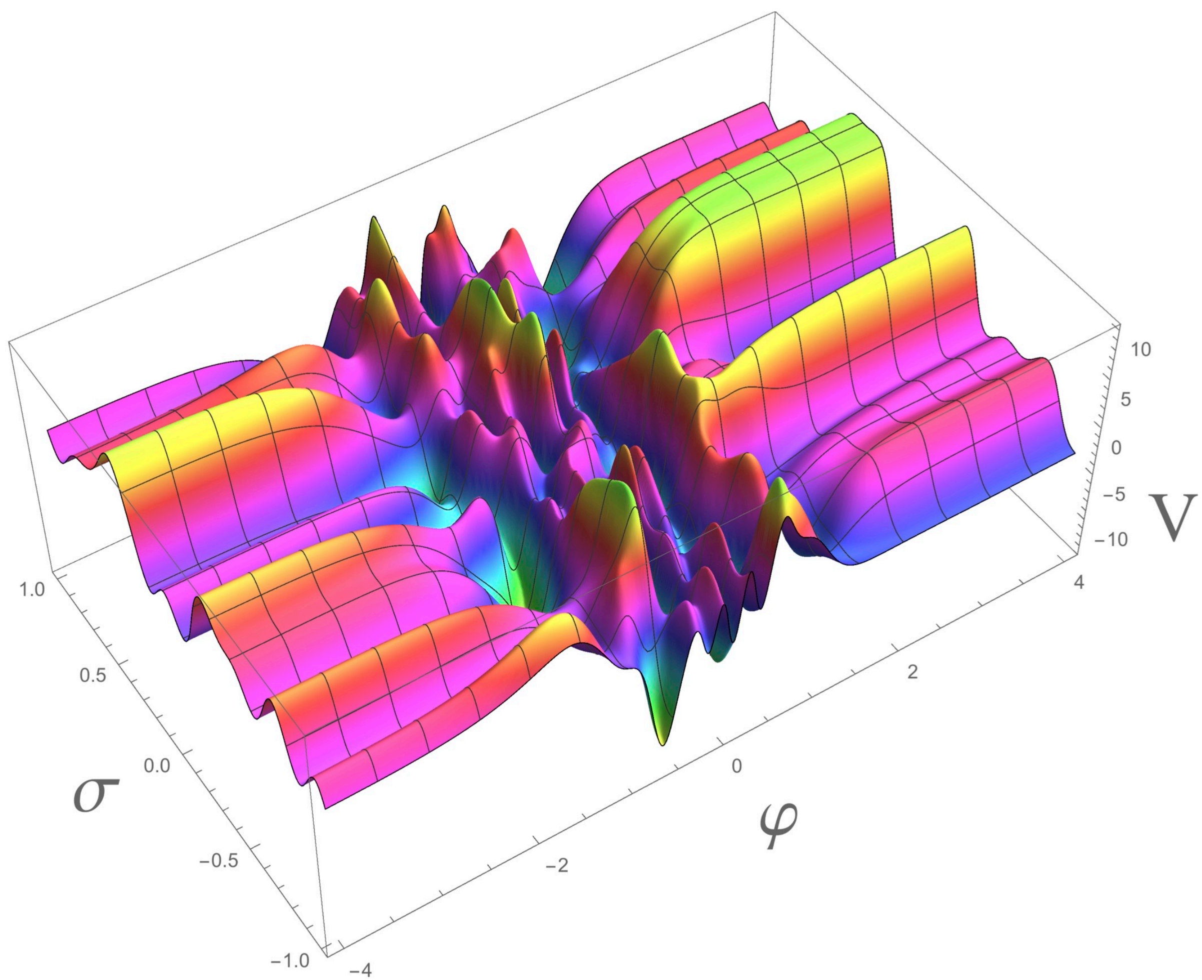
Inflation with Random Potentials and Cosmological Attractors

$$\frac{1}{\sqrt{-g}}\mathcal{L} = \frac{R}{2} - \frac{(\partial_\mu \phi)^2}{2(1-\frac{\phi^2}{6\alpha})^2} - \frac{(\partial_\mu \sigma)^2}{2} - V(\phi,\sigma)$$



In terms of canonical fields φ with the kinetic term $\frac{(\partial_\mu\varphi)^2}{2}$, the potential is

$$V(\varphi,\sigma) = V(\sqrt{6\alpha}\,\tanh\frac{\varphi}{\sqrt{6\alpha}},\sigma)$$



α-attractor mechanism makes the potentials flat, which makes inflation possible, which makes the universe flat

E-models of α-attractors

Kallosh, AL, Roest 2014

Start with the model

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{R}{2} - \frac{3\alpha}{4}\frac{(\partial\rho)^2}{\rho^2} - V(\rho)$$

Switch to canonical variables

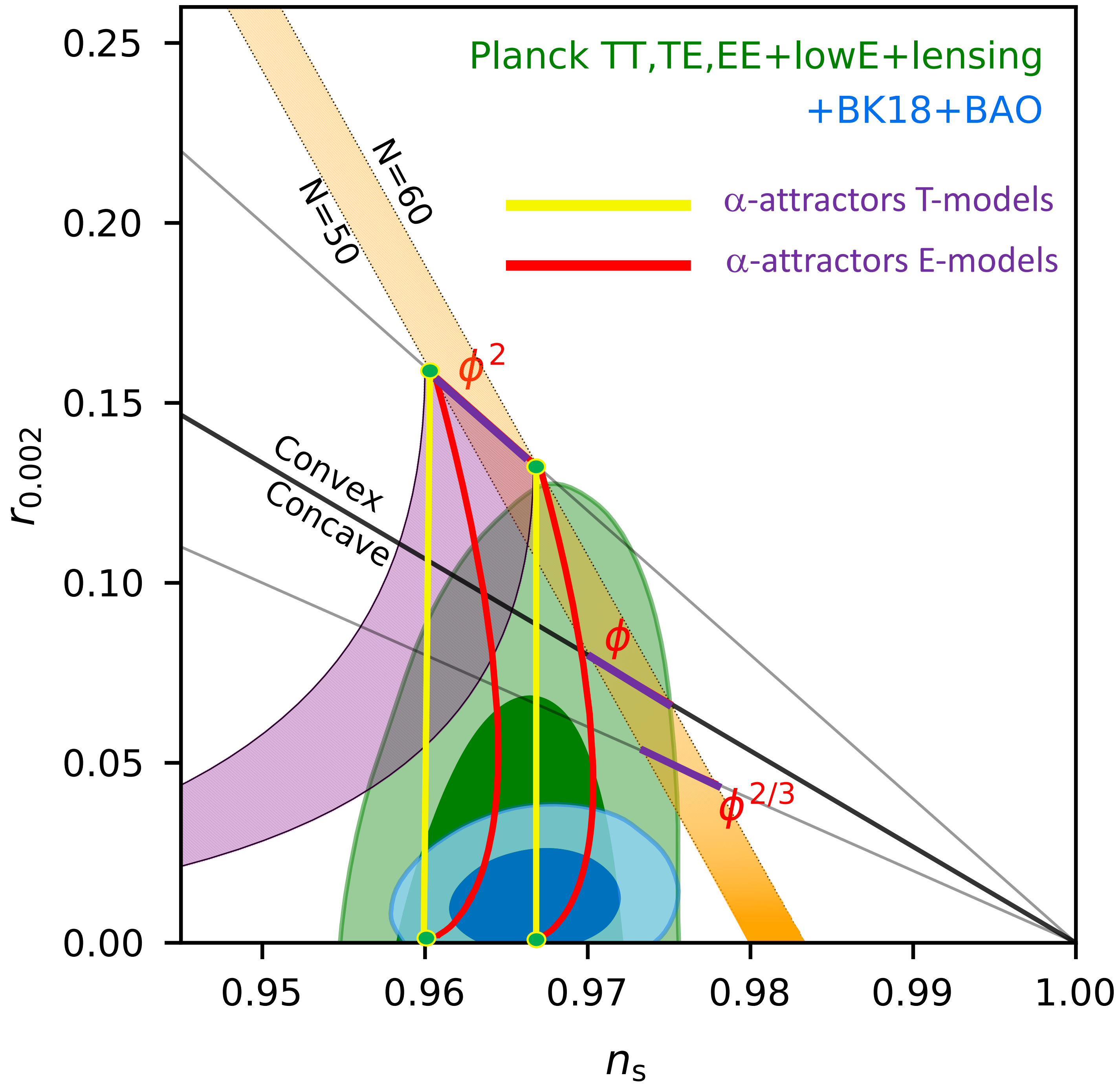
$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{R}{2} - \frac{1}{2}(\partial\varphi)^2 - V(e^{-\sqrt{\frac{2}{3\alpha}}\varphi}).$$

In particular, for $V(\rho) = V_0(1-\rho)^2$ the potential becomes

$$V = V_0\left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\varphi}\right)^2$$

This model (E-model) coincides with the Starobinsky model for α =1. In general case these models predict

$$n_s = 1 - \frac{2}{N_e}\,, \qquad r = \frac{12\alpha}{N_e^2}$$



Planck TT,TE,EE+lowE+lensing
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N=60
N=50
α-attractors T-models
α-attractors E-models
ϕ^2
Convex
Concave
ϕ
$\phi^{2/3}$
0.25
0.20
0.15
0.10
0.05
0.00
$r_{0.002}$
0.95
0.96
0.97
0.98
0.99
1.00
n_s

General pole inflation

Galante, Kallosh, AL, Roest 2014

Start with the model

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{R}{2} - \frac{a_q}{2}\frac{(\partial\rho)^2}{\rho^q} - V(\rho)$$

For q > 2 and small r one has an attractor regime with

$$n_s = 1 - \frac{\beta}{N_e}\,, \qquad \beta = \frac{q}{q-1}$$

Some of these models have interpretation in terms of Dp brane inflation (KKLTI models) Dvali, Tye, 1998, Kachru, Kallosh, A.L., Maldacena, McAllister, Trivedi 2003, Kallosh, A.L. Yamada 1811.01023

$$V_{Dp-\bar{D}p} \sim \frac{\varphi^k}{m^k + \varphi^k} = \left(1 + \frac{m^k}{\varphi^k}\right)^{-1}, \qquad k = 7 - p = \frac{2}{2-q}$$

General pole inflation

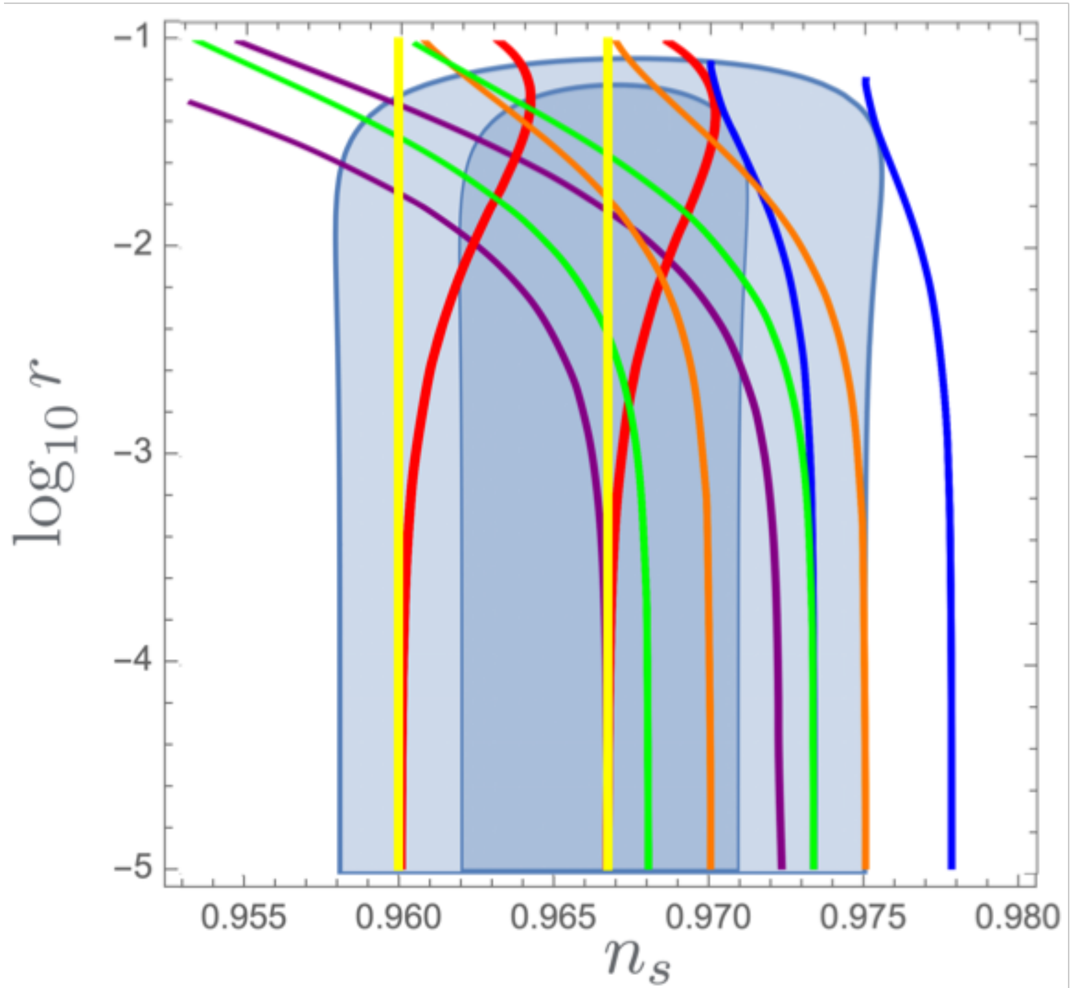
In particular, for D3 branes and small m one has

$$V = V_0 \, \frac{\varphi^4}{m^4 + \varphi^4} \,, \qquad n_s = 1 - \frac{5}{3N} \,, \qquad r = \frac{4m^{\frac{4}{3}}}{(3N)^{\frac{5}{3}}}$$

For D5 branes and small m one has

$$V = V_0 \, \frac{\varphi^2}{m^2 + \varphi^2} \,, \qquad n_s = 1 - \frac{3}{2N_e} \,, \qquad r = \frac{\sqrt{2}\, m}{N_e^{\frac{3}{2}}}$$

The last potential emerges also in the model of two interacting fields with the flattening mechanism introduced by Dong, Horn, Silverstein and Westphal in 2011



From left to right, we show predictions of T-models and E-models (yellow and red lines for N_e = 50, 60) and of Dp brane inflation with p = 3, 4, 5, 6 (purple, green, orange and blue lines). These models, belonging to the general class of pole inflation, can describe gravitational waves all the way down to r =0.

ξ-attractors and other models with non-minimal coupling to gravity

Kallosh, AL, Roest 2013

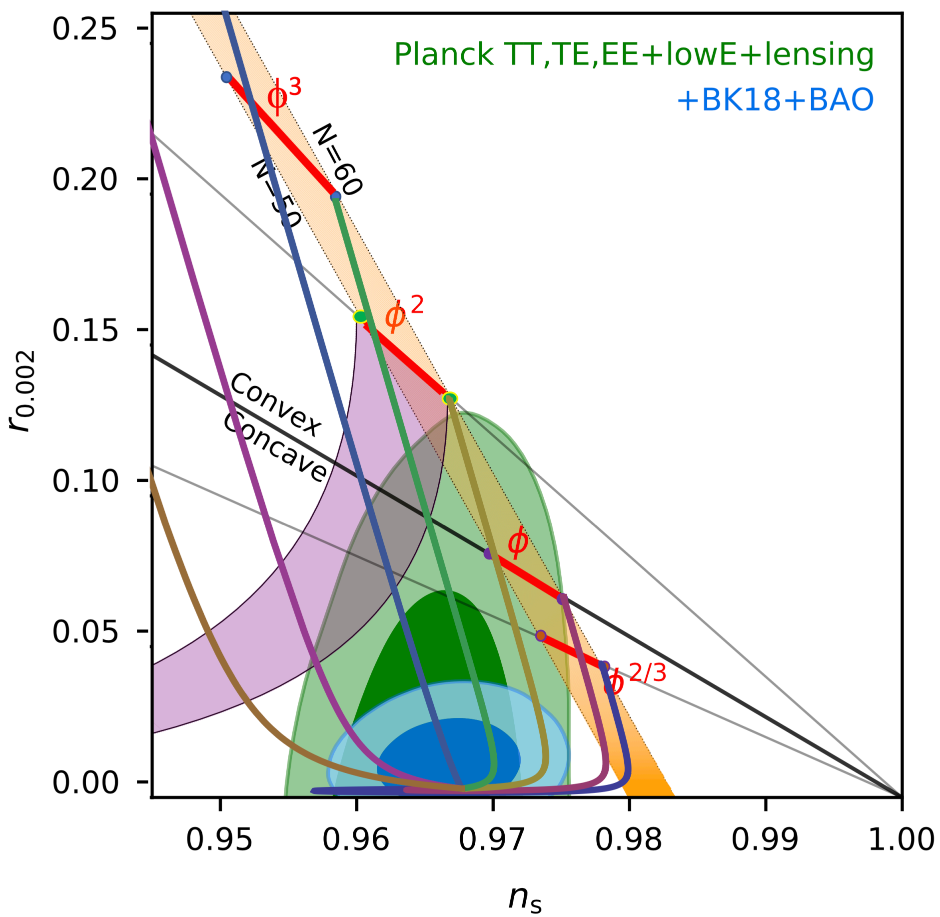
Start with the model

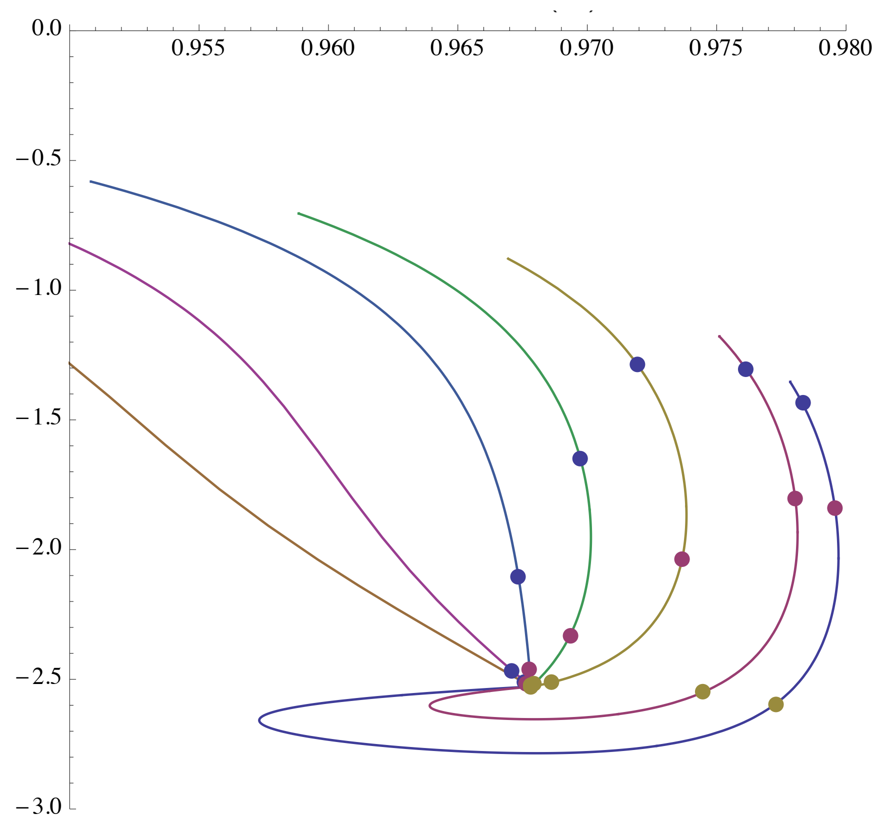
$$\frac{\mathcal{L}_{\rm J}}{\sqrt{-g}} = \frac{1}{2}\big(1 + \xi f(\phi)\big) R - \frac{1}{2}(\partial\phi)^2 - \lambda^2 f^2(\phi)$$

For f = ϕ^2 this model would coincide with Higgs inflation proposed by Bezrukov and Shaposhnikov. Here we consider **a general function f(ϕ)**, and nevertheless the predictions at large ξ coincide with the predictions of the Higgs inflation.

$$n_s = 1 - \frac{2}{N_e}, \qquad r = \frac{12}{N_e^2}$$

Monomial potentials and ξ-attractors





Unlike predictions of α-attractors, predictions of ξ-attractors do not go below $r = 10^{-3}$

Relation between α-attractors and models with non-minimal coupling to gravity

Galante, Kallosh, AL, Roest 2014

Consider with the model

$$\frac{\mathcal{L}_{\rm J}}{\sqrt{-g}} = \frac{1}{2}\Omega(\phi)R - \frac{1}{2}K_{\rm J}(\phi)(\partial\phi)^2 - V_{\rm J}(\phi)$$

with

$$K_{\rm J} = \frac{1}{4\xi}\frac{(\Omega')^2}{\Omega}\,, \qquad V_{\rm J}(\phi) = \Omega^2\, U(\Omega)$$

In the Einstein frame this theory becomes an α-attractor for the field Ω

$$\mathcal{L}_E = \sqrt{-g}\left[\frac{R}{2} - \frac{3\alpha}{4}\left(\frac{\partial\Omega}{\Omega}\right)^2 - U(\Omega)\right]$$

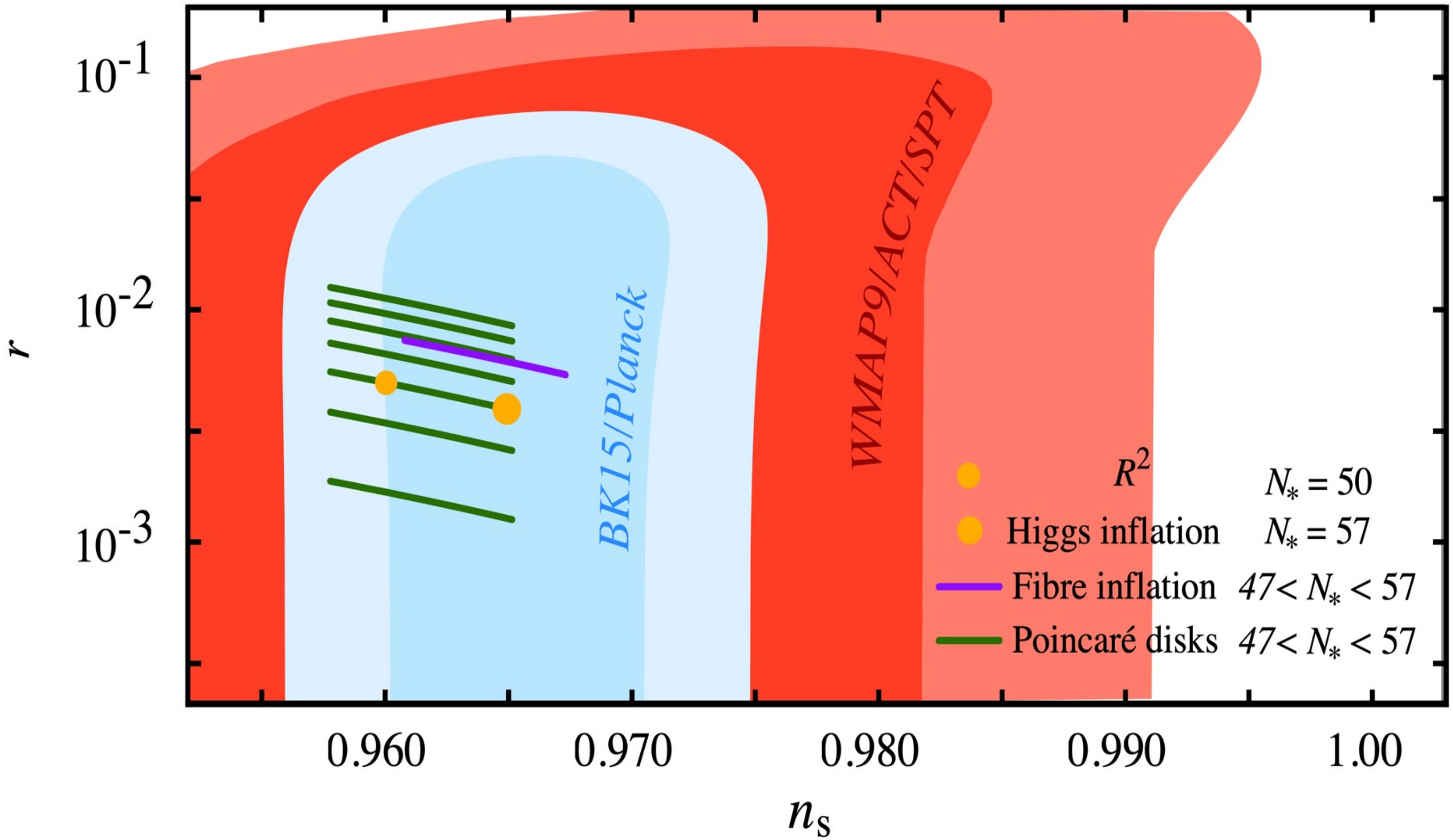
with

$$\alpha \equiv 1 + \frac{1}{6\xi}$$

In these models one can also describe any small values of r, all the way down to r = 0.

Special cases

Fig from R. Flauger talk at CMB-S4

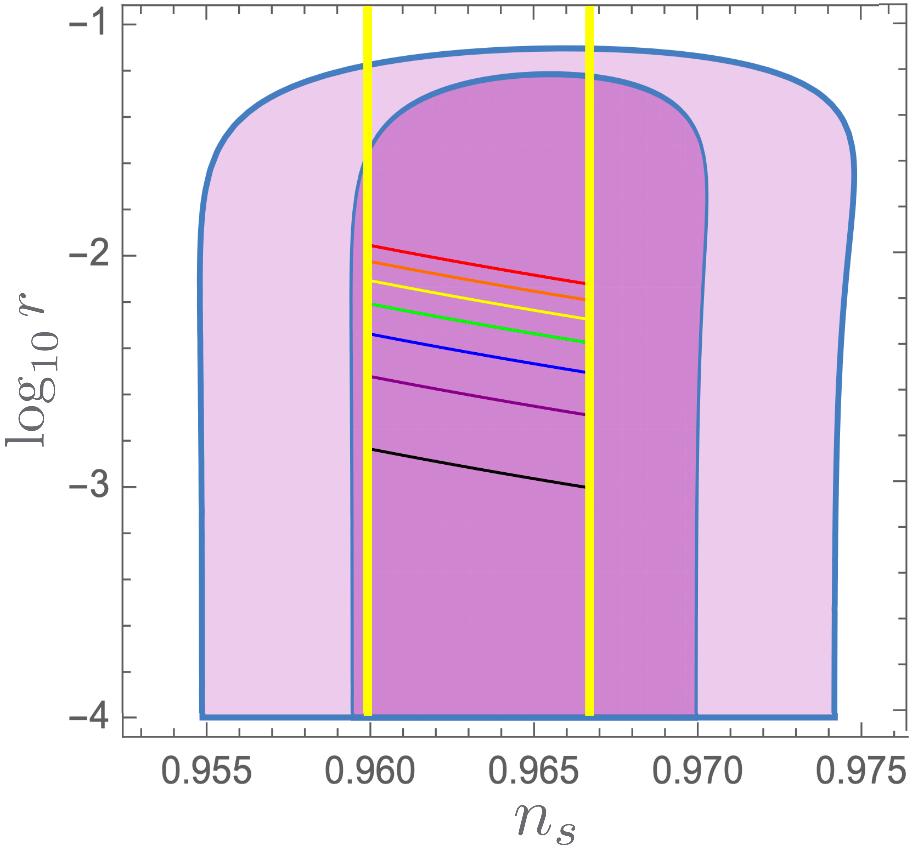


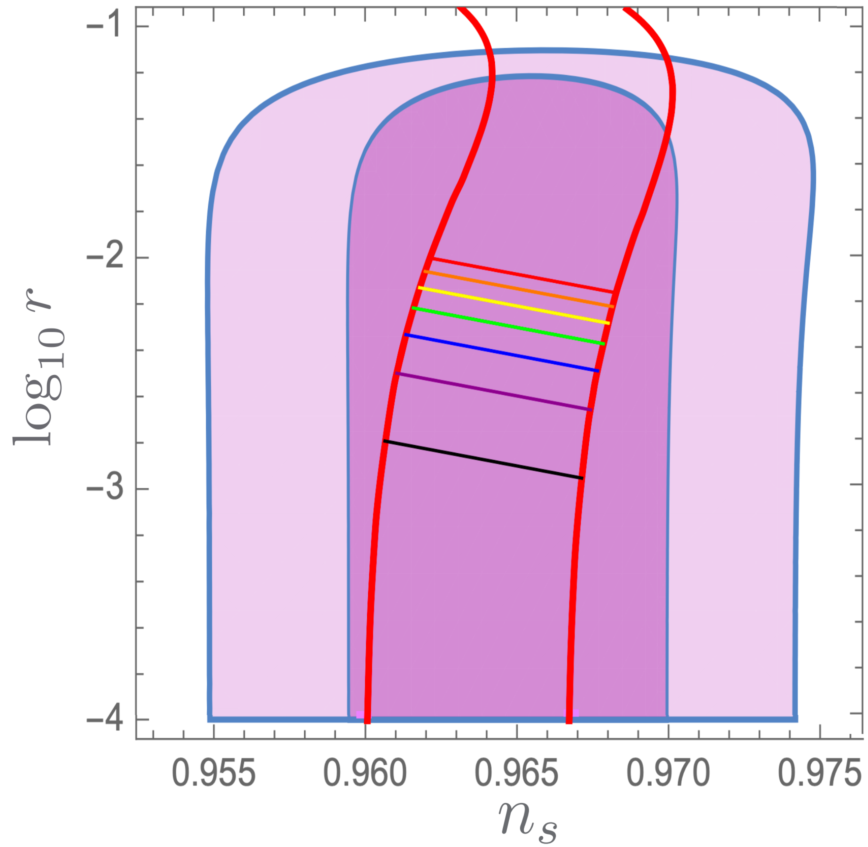
7 discrete targets for **α-attractors** (Kallosh, AL, Roest 2014, Ferrara, Kallosh 2016) and **fibre inflation** (Cicoli, Burgess, Quevedo 2008) are among the main targets for B-mode searches, along with the **Starobinsky** model and **Higgs** inflation

Benchmarks for T-models and E-models

T-models $V_T = V_0 \tanh^2 \frac{\varphi}{\sqrt{6\alpha}}$

E-models $V_E = V_0 \left(1 - e^{\sqrt{\frac{2}{3\alpha}}\varphi}\right)^2$

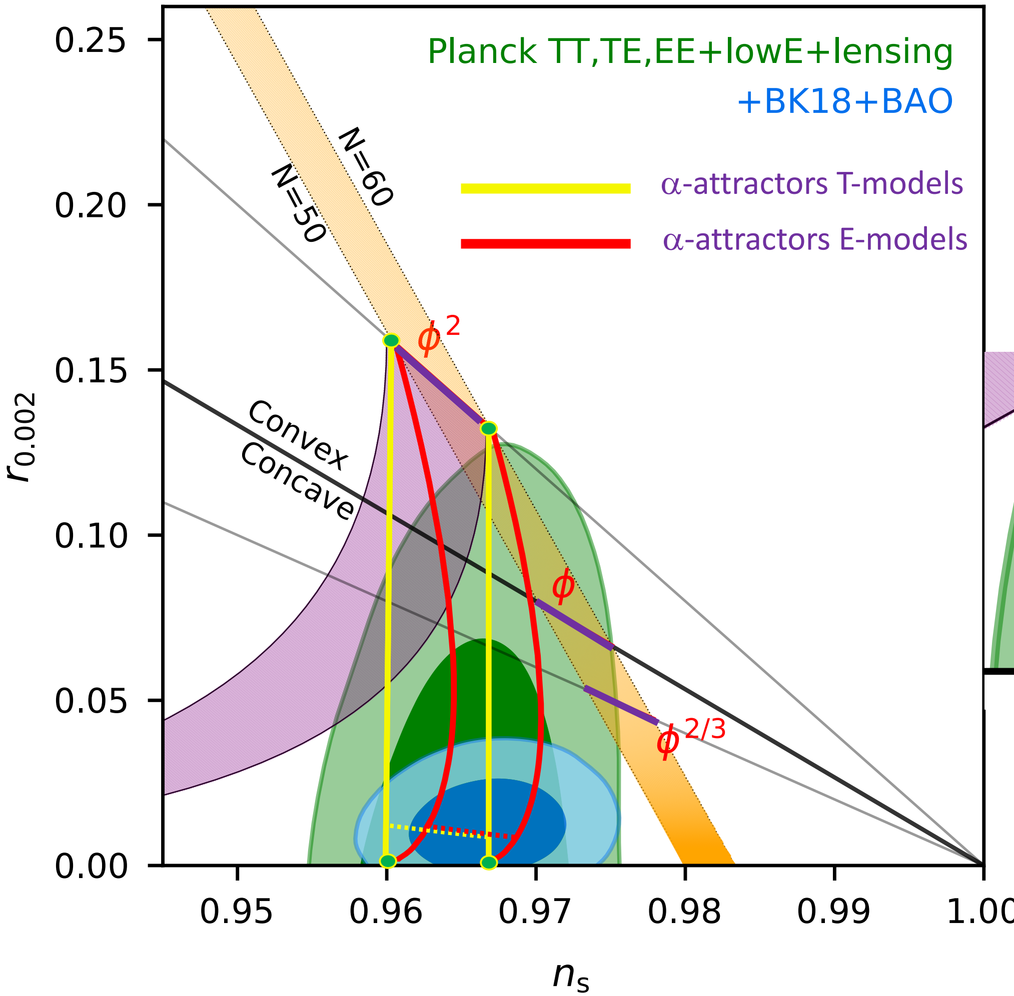




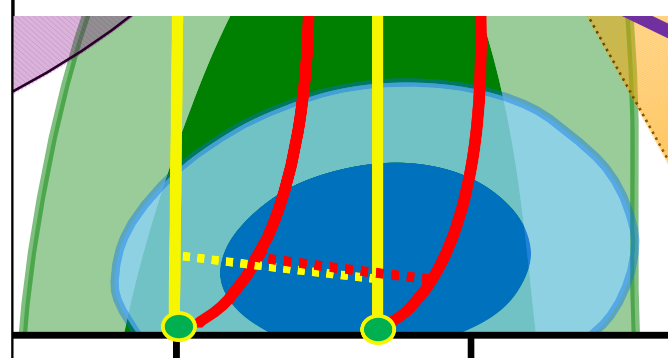
String theory interpretation of 7 discrete targets for α-attractors

Ferrara, Kallosh 1610.04163. Kallosh, A.L., Wrase, Yamada 1704.04829

BICEP/Keck2021 do not claim a discovery of the gravitational waves. The error bars of their result $r_{0.05} = 0.014^{+0.010}_{-0.011}$ are too large, $\sigma(r) = 0.009$. However, it is quite intriguing that the yellow and red dashed lines, which show the predictions of the largest option α = 7/3, go straight through the center of the dark blue ellipse favored by Planck/BICEP/Keck data.



BICEP/Keck hope to reach σ(r) = 0.003 within 5 years.



Inflation in supergravity

Main problem:

$$V(\phi) = e^{K}\left(K^{-1}_{\Phi\bar{\Phi}}\,|D_{\Phi}W|^2 - 3|W|^2\right)$$

Canonical Kahler potential is $K = \Phi\bar{\Phi}$

Therefore, the potential blows up at large $|\Phi|$, and slow-roll inflation is impossible:

$$V \sim e^{|\Phi|^2}$$

Too steep, no inflation…

A general solution

Kallosh, A.L. 2010, Kallosh, A.L., Rube, 2010

$$W = X\, f(\Phi)$$

Superpotential must be a REAL holomorphic function. (We must be sure that the potential is symmetric with respect to Im Φ, so that Im Φ = 0 is an extremum (then one should check that it is a minimum). The Kahler potential is any function of the type

$$\mathcal{K}((\Phi - \bar{\Phi})^2,\, X\bar{X})$$

The potential as a function of the real part of Φ at X = 0 is

$$V = |f(\Phi)|^2$$

FUNCTIONAL FREEDOM in choosing inflationary potential

This method and its generalizations are especially powerful if X is a nilpotent field, $X^2=0$.

Antoniadis, Dudas, Ferrara, Sagniotti 2014
Ferrara, Kallosh, A.L. 2014

Model-building Paradise

Kallosh, A.L, Roest, Yamada 1705.09247;
Gunaydin, Kallosh, A.L, Yamada 2008.01494,
Kallosh, A.L, Wrase, Yamada 2108.08491, 2108.08492

Consider a theory with a Kahler potential

$$K(T,\overline{T}) = K_0(T,\overline{T}) + \frac{F_X^2}{F_X^2 + V_{\rm infl}(T,\overline{T})} X\overline{X}$$

and superpotential

$$W = (W_0 + F_X X)\, e^{-\kappa(T)/2}$$

Here X is a nilpotent field, and

$$\kappa(T) \equiv K_0(T,\overline{T})_{|_{\overline{T}\to T}}$$

Then the potential along the direction $T = \overline{T} = t$ is given by

$$V_{\rm total}(T) = \Lambda + V_{\rm infl}(T,\overline{T})_{|_{T=\overline{T}=t}}$$

and the cosmological constant is

$$\Lambda = F_X^2 - 3W_0^2$$

Example: single-field α-attractor

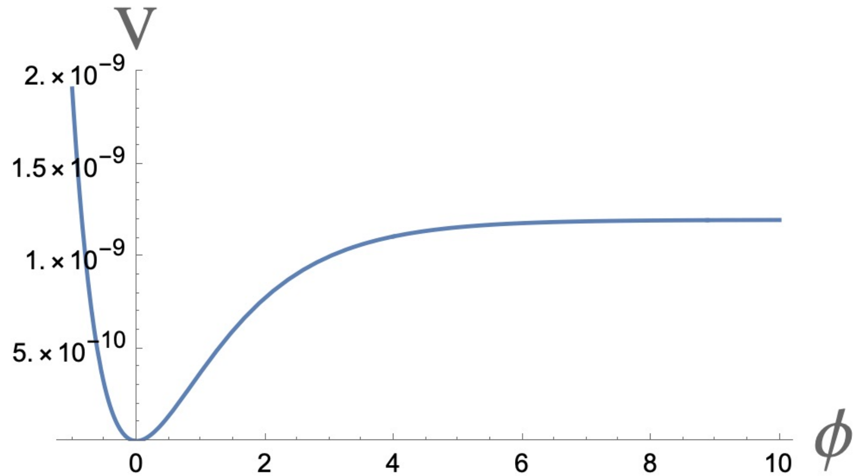
$$K(T,\overline{T}) = -3\alpha\log(T+\overline{T}) + \frac{F_X^2}{F_X^2 + V_{\text{infl}}(T,\overline{T})}X\overline{X}$$

$$W(T) = (W_0 + F_X X)\sqrt{2T}$$

$$V_{\text{infl}} = m^2(1-T)(1-\overline{T})$$

In canonical variables, along the real T flat direction one has the α-attractor potential

$$V_{\text{total}}(\phi) = \Lambda + m^2\left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\phi}\right)^2$$



Towards sequestered inflation

The same results remain true in the theory with many moduli $\mathrm{T_i}$ if we add to the superpotential any function $W^{(I)}(T_i)$ such that

$$W^{(I)}(T_i) = 0 \,, \qquad \partial_{T_j} W^{(I)}(T_i) = 0$$

along the direction $T_i = \overline{T}_i = t_i$

In the absence of the nilpotent field X, this theory would describe supersymmetric Minkowski flat directions, but in our construction the potential along the flat (inflaton) directions is given by

$$V_{\rm total}(T_i) = \Lambda + V_{\rm infl}(T_i, \overline{T}_i)|_{T_i = \overline{T}_i = t_i}$$

Importantly, this potential does NOT depend on the value of the superpotential $W^{(I)}(T_i)$ outside of the flat inflaton directions.

This allows to disentangle, sequester, dynamics of inflation from the large energy scale encoded in $W^{(I)}(T_i)$.

IIB string theory: STU model

Kallosh, A.L, Wrase, Yamada 2108.08492

$$
\begin{aligned}
W =& e_0 + \mathrm{i}\sum_{I=1}^{3} e_I U_I - \sum_{I=1}^{3} q_I \frac{U_1U_2U_3}{U_I} + \mathrm{i} m U_1U_2U_3 \\
&+ S\left[\mathrm{i}h_0 - \sum_{I=1}^{3} a_I U_I + \sum_{I=1}^{3} \bar{a}_I \frac{U_1U_2U_3}{U_I} - \bar{h}_0 U_1U_2U_3\right] \\
&+ \sum_{I=1}^{3} T_I\left[-\mathrm{i}h_I - \sum_{J=1}^{3} U_J b_{JI} + \sum_{J=1}^{3} \mathrm{i}\bar{b}_{JI}\frac{U_1U_2U_3}{U_J} + \bar{h}_I U_1U_2U_3\right] - S\sum_{I=1}^{3} f_I T_I \\
&+ \sum_{I,J=1}^{3} \mathrm{i} g_{JI} S U_J T_I + \sum_{I,J=1}^{3} \bar{g}_{JI} S T_I \frac{U_1U_2U_3}{U_J} - \mathrm{i} S U_1U_2U_3 \sum_{I=1}^{3} \bar{f}_I T_I\,.
\end{aligned}
$$

Superpotential due to Aldazabal, Camara, Font and Ibanez, 2006

Tadpole cancellation: Bianchi Identities in 10D supergravity with local sources

$$
\begin{aligned}
N_{\mathrm{D3}} &= 16 - \frac{1}{2}\left[m h_0 - e_0 \bar{h}_0 + \sum_{I=1}^{3}(q_I a_I + e_I \bar{a}_I)\right]. \\
N_{\mathrm{NS7}_I} &= \frac{1}{2}\left[h_0 \bar{f}_I - \bar{h}_0 f_I - \sum_{J=1}^{3}(\bar{a}_J g_{JI} - a_J \bar{g}_{JI})\right] \\
N_{\mathrm{I7}_I} &= -\frac{1}{2}\left[e_0 \bar{f}_I - m f_I + \sum_{J=1}^{3}(q_J g_{JI} + e_J \bar{g}_{JI})\right]
\end{aligned}
$$

$$
\begin{aligned}
\bar{h}_0 h_J + \bar{a}_I b_{IJ} + \bar{a}_J \bar{b}_{KJ} - a_K \bar{b}_{KJ} + m f_J - q_I g_{IJ} - q_J g_{JJ} - e_K \bar{g}_{KJ} &= 0, \\
h_0 \bar{h}_J + a_I \bar{b}_{IJ} + a_J \bar{b}_{JJ} - \bar{a}_K b_{KJ} - e_0 \bar{f}_J - e_I \bar{g}_{IJ} - e_J \bar{g}_{JJ} - q_K g_{KJ} &= 0, \\
\bar{h}_0 b_{KJ} + \bar{a}_I \bar{b}_{JJ} + \bar{a}_J \bar{b}_{IJ} - a_K \bar{h}_J + m g_{KJ} - q_I \bar{g}_{JJ} - q_J \bar{g}_{IJ} - e_K \bar{f}_J &= 0, \\
h_0 \bar{b}_{KJ} + a_I b_{JJ} + a_J b_{IJ} - \bar{a}_K h_J - e_0 \bar{g}_{KJ} - e_I g_{JJ} - e_J g_{IJ} - q_K f_J &= 0.
\end{aligned}
$$

$$
\begin{aligned}
-g_{II} g_{JK} + \bar{g}_{KI} f_K + f_I \bar{g}_{KK} - g_{JI} g_{IK} &= 0, \\
-\bar{g}_{II} \bar{g}_{JK} + g_{KI} \bar{f}_K + \bar{f}_I g_{KK} - \bar{g}_{JI} \bar{g}_{IK} &= 0, \\
-g_{II} \bar{g}_{IJ} + \bar{g}_{JI} g_{JJ} + f_I \bar{f}_J - g_{KI} \bar{g}_{KJ} &= 0, \\
\bar{g}_{II} g_{IJ} - g_{JI} \bar{g}_{JJ} + f_I \bar{f}_J - g_{KI} \bar{g}_{KJ} &= 0.
\end{aligned}
$$

$$
\begin{aligned}
-b_{II} b_{JK} + \bar{b}_{KI} h_K + h_I \bar{b}_{KK} - b_{JI} b_{IK} &= 0, \\
-\bar{b}_{II} \bar{b}_{JK} + b_{KI} \bar{h}_K + \bar{h}_I b_{KK} - \bar{b}_{JI} \bar{b}_{IK} &= 0, \\
-b_{II} \bar{b}_{IJ} + \bar{b}_{JI} b_{JJ} + h_I \bar{h}_J - b_{KI} \bar{b}_{KJ} &= 0, \\
\bar{b}_{II} b_{IJ} - b_{JI} \bar{b}_{JJ} + h_I \bar{h}_J - b_{KI} \bar{b}_{KJ} &= 0.
\end{aligned}
$$

$$
\begin{aligned}
b_{KK} \bar{g}_{KJ} - h_K \bar{f}_J - \bar{b}_{JK} g_{JJ} + b_{IK} \bar{g}_{IJ} + g_{KK} \bar{b}_{KJ} - f_K \bar{h}_J - \bar{g}_{JK} b_{JJ} + g_{IK} \bar{b}_{IJ} &= 0, \\
b_{KK} g_{IJ} - h_K \bar{g}_{JJ} - \bar{b}_{JK} f_J + b_{IK} g_{KJ} + g_{KK} b_{IJ} - f_K \bar{b}_{JJ} - \bar{g}_{JK} h_J + g_{IK} b_{KJ} &= 0, \\
\bar{b}_{KK} \bar{g}_{IJ} - \bar{h}_K g_{JJ} - b_{JK} \bar{f}_J + \bar{b}_{IK} \bar{g}_{KJ} + \bar{g}_{KK} \bar{b}_{IJ} - \bar{f}_K b_{JJ} - g_{JK} \bar{h}_J + \bar{g}_{IK} \bar{b}_{KJ} &= 0, \\
\bar{b}_{KK} g_{KJ} - \bar{h}_K f_J - b_{JK} \bar{g}_{JJ} + \bar{b}_{IK} g_{IJ} + \bar{g}_{KK} b_{KJ} - \bar{f}_K h_J - g_{JK} \bar{b}_{JJ} + \bar{g}_{IK} b_{IJ} &= 0.
\end{aligned}
$$

Type IIB string theory and sequestered inflation

Kallosh, A.L, Roest, Yamada 2108.08491, 2108.08492

Seven chiral superfields (S, T_I, U_I) where $I = 1, 2, 3.$

Example of a flux superpotential satisfying tadpole cancellation conditions with supersymmetric Minkowski flat directions

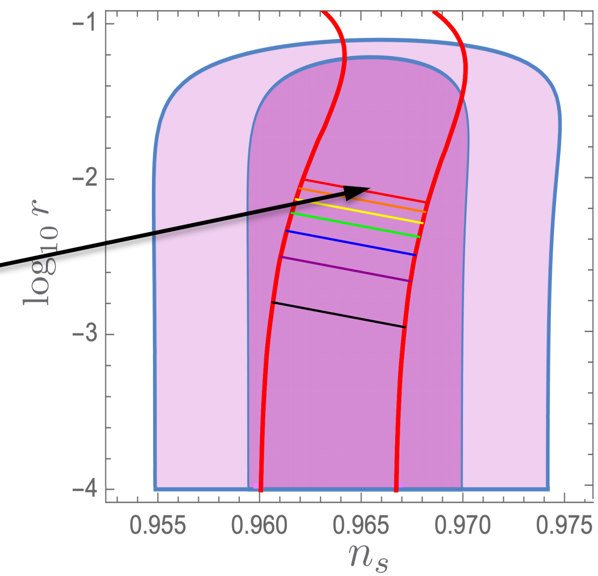
$$W = (S - U_1)(T_1 - U_2) + (S - U_2)(T_2 - U_3) + (S - U_3)(T_3 - U_1)$$

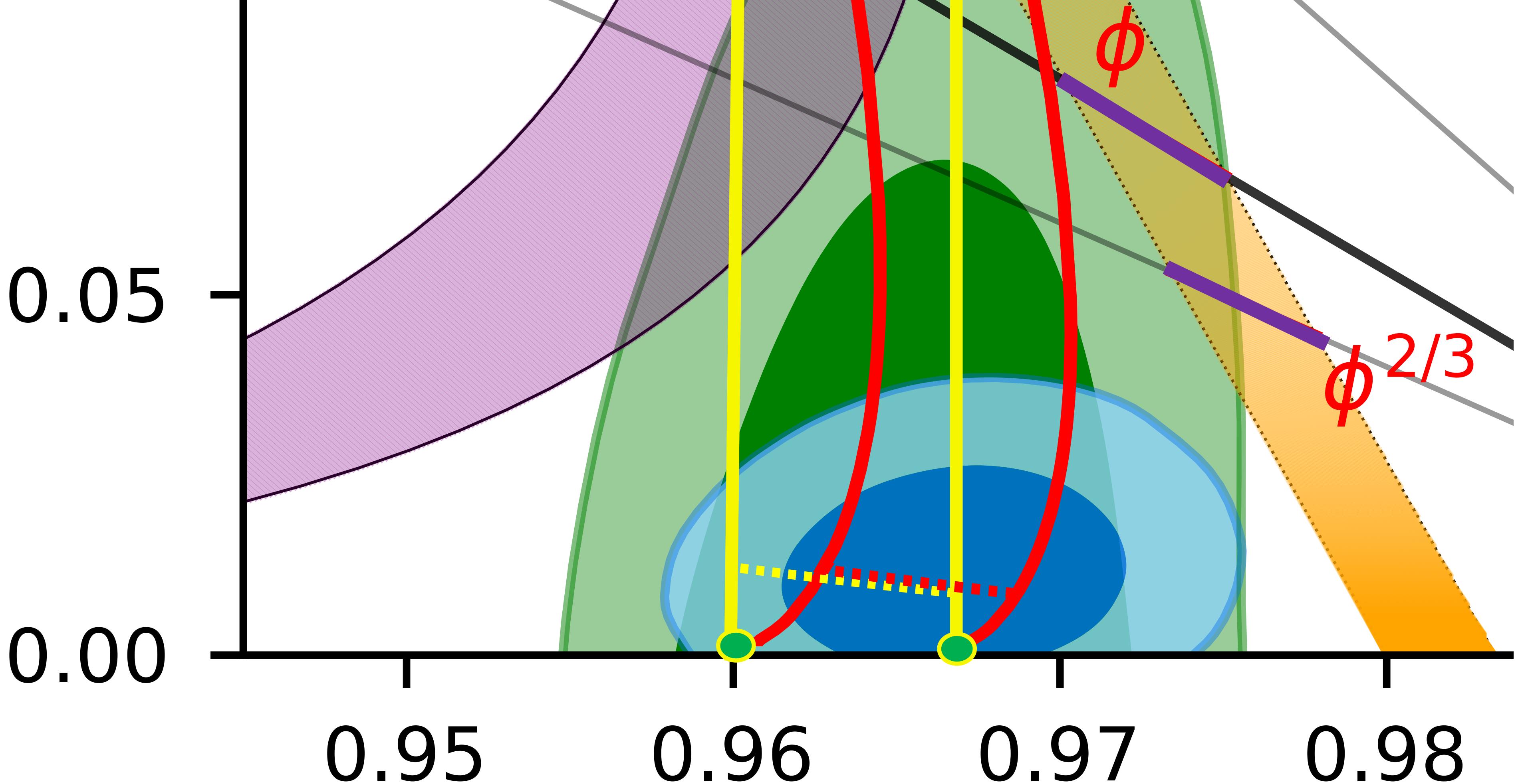
1 flat direction $S = T_1 = T_2 = T_3 = U_1 = U_2 = U_3$

After uplifting of this flat direction and transformation to canonical variables, one finds α-attractor inflationary potential with 3α = 7 and r = 10^{-2}

$$V_{\rm total}(\phi) = \Lambda + m^2 \left(1 - e^{-\sqrt{\frac{2}{7}}\phi}\right)^2$$

Describes the upper nearly horizontal line in this figure





Dashed lines show the value r ~ 0.01 for 3α = 7, the top value of α in α–attractor models inspired by M-theory and string theory

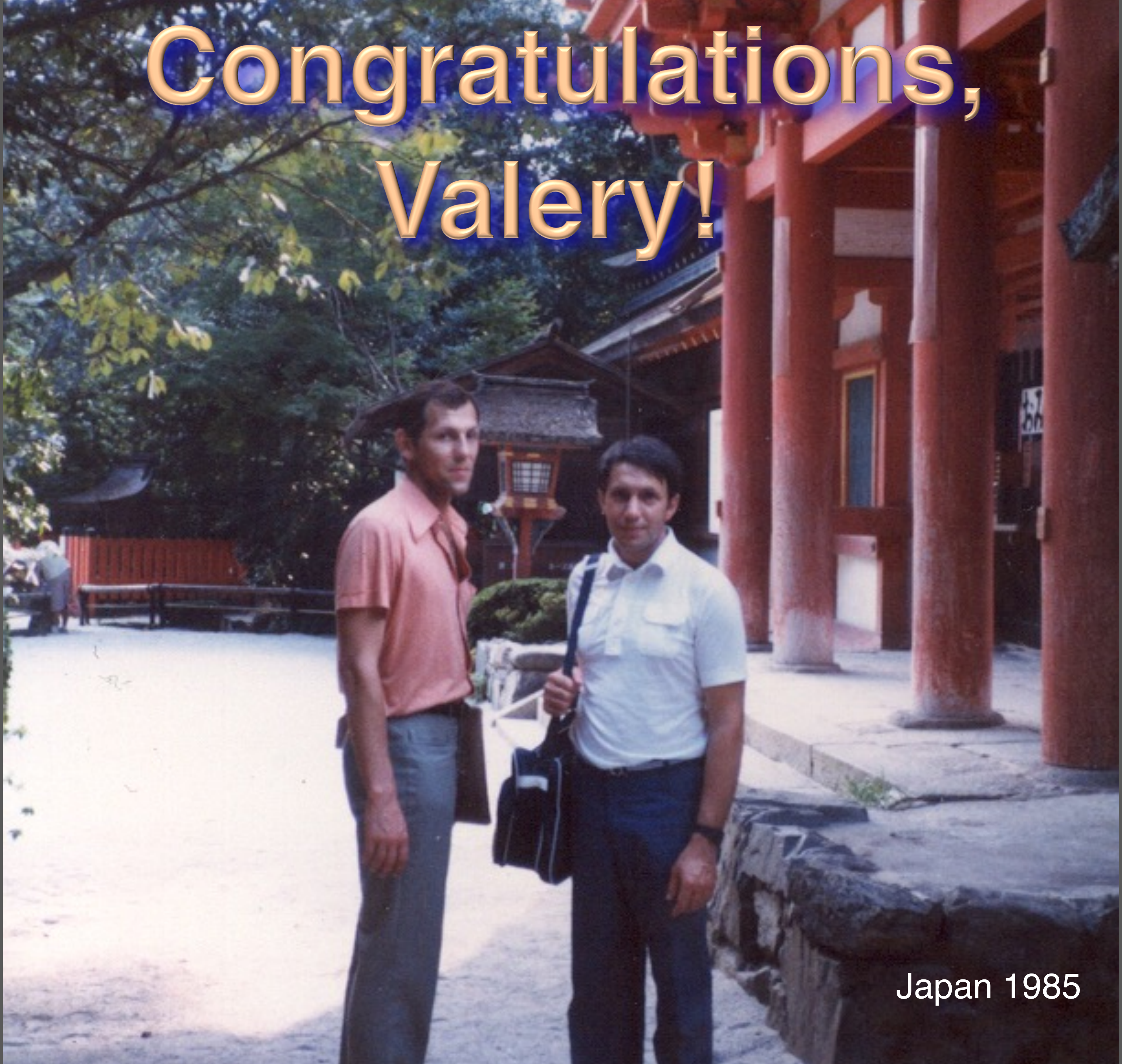
Conclusions:

1. Many predictions of inflationary theory have been tested and confirmed during the last 40 years.

2. Some inflationary models, such as the Starobinsky model, the Higgs inflation, and a broad class of α-attractors, can describe all inflation-related observational data by a single parameter responsible for the amplitude of scalar perturbations. Predictions of α-attractors are very stable with respect to significant modifications of the inflaton potential. These models, as well as more general versions of pole inflation, can describe any small value of r, all the way down to $r = 0$.

3. We constructed supergravity models where phenomenology of inflation is sequestered, protected from the Planckian energy scale physics which can be associated with M-theory or string theory.

4. BICEP/Keck results are moving very close to the range necessary for testing these models.


Congratulations,
Valery!
Japan 1985